POLARIMETRIC SAR INTERFEROMETRY EVALUATION IN MANGROVES

Seung-Kuk Lee, Temilola Fatoyinbo, Batuhan Osmanoglu, Guoqing Sun

Biospheric Sciences Laboratory, NASA Goddard Space Flight Center

ABSTRACT

TanDEM-X (TDX) enables to generate an interferometric coherence without temporal decorrelation effect that is the most critical factor for a successful Pol-InSAR inversion, as have recently been used for forest parameter retrieval. This paper presents mangrove forest height estimation only using single-pass/single-baseline/dual-polarization TDX data by means of new dual-Pol-InSAR inversion technique. To overcome a lack of one polarization in a conventional Pol-InSAR inversion (i.e. an underdetermined problem), the ground phase in the Pol-InSAR model is directly estimated from TDX interferograms assuming flat underlying topography in mangrove forest. The inversion result is validated against lidar measurement data (NASA's G-LiHT data).

Index Terms— *TanDEM-X(TDX), Mangrove, Pol-InSAR*

1. INTRODUCTION

Mangrove forests cover only about 1% of the Earth's terrestrial surface, but they are amongst the highest carbon-storing and carbon-exporting ecosystems globally. Mangroves grow in the intertidal zone periodically flooded by tides and in area where seawater is diluted by high regular rainfall, ground water flows or rivers. Estimating 3-D mangrove forest parameters has been challenging due to the complex physical environment of the forests. In previous works, remote sensing techniques have proven an excellent tool for the estimation of mangrove forests. Recent experiments have successfully demonstrated the global scale estimation of mangrove structure using spaceborne remote sensing data; SRTM (InSAR), ICESat/GLAS (lidar), Landsat ETM+ (optic) [1][2]. However, those systems have had relatively low spatial and temporal resolutions comparing to a conventional satellite SAR systems.

Polarimetric SAR Interferometry (Pol-InSAR) is a SAR remote sensing technique based on the coherent combination of both polarimetric and interferometric observables [3]. The Pol-InSAR techniques have provided a step forward in quantitative 3-D forest parameter estimation (e.g. forest canopy height and biomass) over a variety of forests. In last years, the quantitative models from Pol-InSAR data has been demonstrated primarily using airborne repeat-pass fully polarimetric interferometric systems at L- and P-band and more recently even at X-band. Current experiments at X-band have successfully proven the potential to estimate 3-D forest parameters using Pol-InSAR data although X-band has been expected to be less sensitive to vertical forest structure [6].

The paper will provide the improved estimation of mangrove forest parameters using high-resolution dual-pol (HH/VV) TanDEM-X data sets by means of Pol-InSAR. In the next section, Pol-InSAR inversion will be briefly reviewed and the constraint of dual-Pol-InSAR will be introduced and recovered by a new approach estimating the ground phase in mangrove.

2. POL-INSAR INVERSION: QUAD- VS. DUAL-POL

2.1. Quad- vs. Dual-Pol-InSAR Inversion

A quantitative estimation of forest parameters can be done by using the so-called Random Volume over Ground (RVoG) model [3][4][5] – a two-layer model. According to the RVoG model, the coherence loci $\tilde{\gamma}(\vec{w})$ at different polarizations $\vec{w}$ depend on different amounts of ground contribution $m(\vec{w})$ and represent a straight line in the complex plain [5]:

$$\tilde{\gamma}(\vec{w}) = e^{i\varphi_0}\,\frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})} = e^{i\varphi_0}\left(\tilde{\gamma}_V + \frac{m(\vec{w})}{1+m(\vec{w})}(1-\tilde{\gamma}_V)\right)$$

$$\text{where} \qquad (1)$$

$$\tilde{\gamma}_V = \frac{\int_0^{h_v} \exp(2\sigma z'/\cos\theta_0)\exp(i\kappa_z z')dz'}{\int_0^{h_v} \exp(2\sigma z'/\cos\theta_0)dz'}$$

where $\varphi_0 (= \kappa_z z_0)$ is the phase related to the underlying topography z_0 . $\tilde{\gamma}_V$ represents a volume-only coherence and is a function of forest parameters (i.e. forest height

h_v and extinction σ) and the SAR geometry (i.e. vertical wave number κ_z and incidence angle θ_0) [6].

Equation (1) can be inverted in terms of a quad-polarization single-baseline acquisition [3][4][5][6]. The inversion problem has a unique solution and is balanced with three measured complex interferometric coherences [$\tilde{\gamma}(\vec{w}_1)$ $\tilde{\gamma}(\vec{w}_2)$ $\tilde{\gamma}(\vec{w}_3)$] each for any independent polarization channel and five unknowns (h_v , σ , m_1 , m_2 , φ_0), assuming no response from the ground in one polarization (i.e. $m_3 = 0$) [6].

$$\min_{h_v,\sigma,m_1,m_2,\varphi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\vec{w}_1) \\ \tilde{\gamma}(\vec{w}_2) \\ \tilde{\gamma}(\vec{w}_3) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}(h_v,\sigma,m_1(w_1)) \\ \tilde{\gamma}(h_v,\sigma,m_2(w_2)) \\ \tilde{\gamma}_V e^{i\varphi_0} \end{bmatrix} \right\| \tag{2}$$

However, in case of dual-polarization single-baseline acquisition, only two measured complex interferometric coherences [$\tilde{\gamma}(\vec{w}_1)$ $\tilde{\gamma}(\vec{w}_2)$] are available for four unknown parameters (h_v , σ , m_1 , φ_0) even with the assumption of no ground contribution in a polarization (i.e. $m_2 = 0$).

$$\min_{h_v,\sigma,m_1,\varphi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\vec{w}_1) \\ \tilde{\gamma}(\vec{w}_2) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}(h_v,\sigma,m_1(w_1)) \\ \tilde{\gamma}_V e^{i\varphi_0} \end{bmatrix} \right\| \tag{3}$$

Note that equation (3) leads to an underdetermined problem. Possible solutions to enforce the problem are to use external Digital Terrain Models (DTMs) or to fix the extinction value to reduce one unknown in (3) (i.e. φ_0 or σ) [6]. However, high resolution DTM does not always exist over mangrove forests and strong variation of the (mean) extinction value across forest leads to biased forest heights [6].

2.2. Ground Phase Estimation

In this work, one obvious approximation towards the problem is to discard that the underlying topography in mangrove forests is negligible and flat due to the unique growth environment (i.e. water surface). The ground phase can be estimated using interferometric phases on double-bounce dominant target in the boundary of mangrove forest. To find the target dominated by the double-bounce scattering, parameters for SAR and Polarimetry (e.g. signal-to-noise ratio (SNR), coherent scatterer (CS) and the phase difference between HH and VV) were suggested in this study. The actual SNR is directly related to the strength of the returned radar signal [7]. Reflectivity from water bodies (under low wind conditions) is generally much smaller than one from vegetated areas (e.g. forest, agricultural field). Therefore, the boundary between mangrove forest and water bodies (e.g. river, lake, lagoon, swamp) in the image was first extracted using SNR decorrelation [7][8]. And the phase of water surface was then estimated only on pixels selected by co-polar polarimetry and CS technique [9]. Fig. 1 left shows the selected pixels (red) in order to estimate underlying topography in mangrove. The histogram of the estimated phase on the target is shown in Fig. 2.

With the estimated ground phase (φ_0 = -24°) over mangrove forest area, the inversion problem in dual-polarization single-baseline acquisition is finally balanced with three unknowns (h_v , σ , m_1) and two independent complex coherences [$\tilde{\gamma}(\vec{w}_1)$ $\tilde{\gamma}(\vec{w}_2)$].

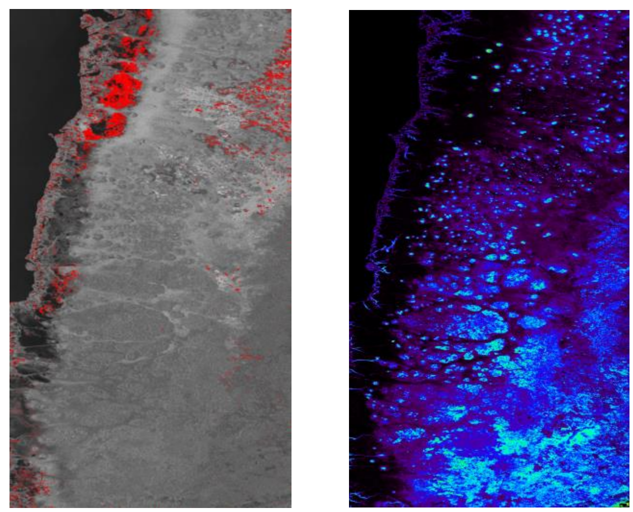

Figure 1 (Left) Selected pixels (red) for estimating underlying topography; (Right) The phase of volume coherence in (1) after removing the ground phase, scaled from 0 to π.

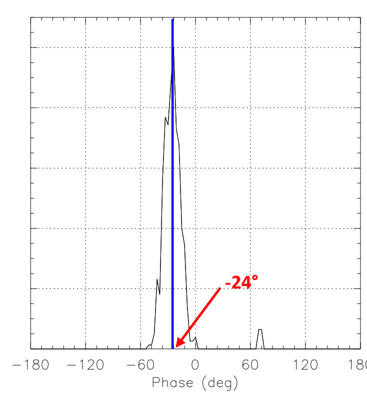

Figure 2 Histogram of the estimated ground phase.

3. TEST SITE AND DATA SET

Campeche test site is located on the west side of Yucatan peninsula, Mexico (20°06'57"N, 90°25'46"W). The site is a wetland that includes estuary and adjacent lagoons. The average total tidal fluctuation is about 2 meters.
For this study, we have used a single-pass dual-polarization TanDEM-X data acquired in bistatic mode. The acquisition date was 2014/03/20 and the height of ambiguity was 55.27 m (i.e. $\kappa_z \approx 0.114$). The system bandwidth was 150 MHz and the incidence angle was 35.78°.
Validation of mangrove height estimation was based on lidar measurement data acquired by NASA's G-LiHT (Goddard's LiDAR, Hyperspectral & Thermal Imager) sensor on 29th April 2013.

4. POL-INSAR INVERSION RESULT

Mangrove heights were estimated using a single-baseline dual-Pol-InSAR inversion approach. The topography estimated in 2.2 was used to solve the underdetermined problem in (3). After removing the topography phase, there remains only the phase of volume-only coherence $\tilde{\gamma}_V$ in (1) that is directly used for Pol-InSAR inversion [5][6]. Fig. 2 right shows the phase scaled from 0 to π. The phase from water bodies, roads and open surface has almost zero, but not negative values, while the phase of the vegetated areas shows positive phases depending on volume height (if κ_z > 0).
Fig. 3 shows the Pol-InSAR inversion results over mangrove area, scaled from 0 to 25 m. Two sequential frames of TanDEM-X data were simply combined and displayed on latitude/longitude coordinate. The result of mangrove heights was validated against H100 derived from G-LiHT data. The six frames of G-LiHT acquisition were superimposed on the mangrove height map (see Fig. 3). For the validation, mangrove height maps from lidar and radar were transformed on the same coordinated and divided regularly into 100 m × 100 m subplots which correspond to one hectare. The mean mangrove heights on each subplot from H100 and Pol-InSAR inversion height were obtained to compare each other. The validation plot for 236 samples is shown in Fig. 4 (a): with a correlation coefficient r^2 of 0.838 and an RMSE of 1.538 m, for a height range from 7 m to 21 m. It indicates about 10% estimation accuracy of the mean forest height.
The height of the scattering center is generally located below on the top forest canopy, even at X-band [6]. Fig. 4 (b) and (c) show the comparison of the height of the scattering center and the lidar H100 height at HH and VV channels. The RMSEs of 5.290/5.321 m are lower than the corresponding RMSE of 1.538 m obtained by dual-Pol-InSAR technique while the correlation coefficients r^2 still keep high. It is obvious that the height of phase centers at both HH and VV over mangrove forest at X-band is lower than the top canopy height from lidar H100 or Pol-InSAR inversion height. Moreover, the both phase centers are located below about 1/3 from top canopy height and on a similar height above the ground.

5. SUMMARY

In this study, inversion and validation of Pol-InSAR data over mangrove forests acquired by TanDEM-X (HH and VV) have been presented. In order to solve the underdetermined problem, the underlying topography in mangrove was first estimated using SNR, CS and co-pol

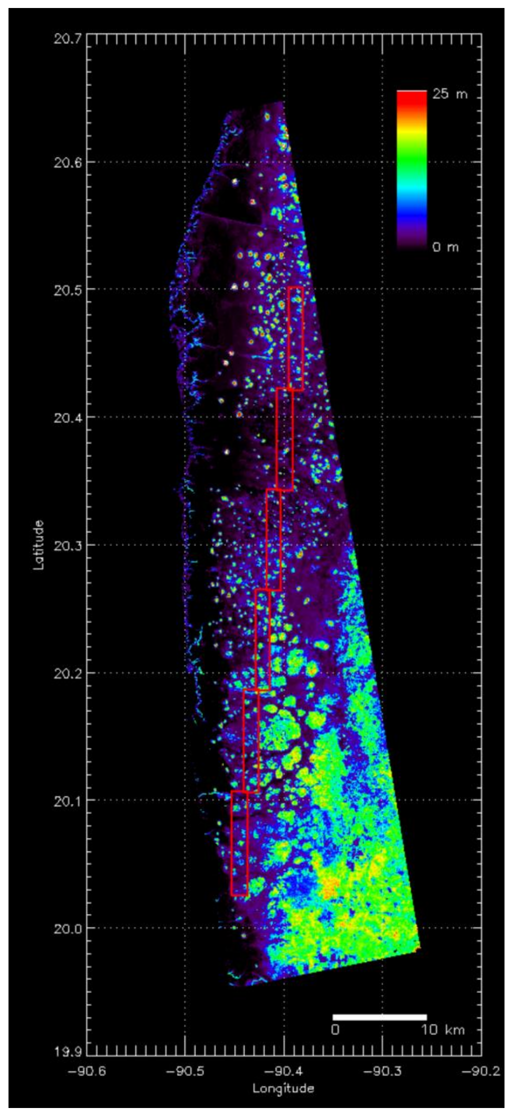

Figure 3 Mangrove height map for Campeche mangrove forest, scaled from 0 to 25 m. Red box represents G-LiHT acquisition frame**.**

phase difference. And then dual-Pol-InSAR inversion has been performed and validated by lidar measurement data. The estimate was characterized by an r^2 of 0.838 and an RMSE of 1.538 m. The result proves a great possibility for mangrove height estimation and a good estimation performance at X-band using dual-pol TanDEM-X data.

6. REFERENCES

[1] T. E. Fatoyinbo and M. Simard, "Height and biomass of mangroves in Africa from ICESat/GLAS and SRTM," *International Journal of Remote Sensing*, Vol. 34:2 pp. 668-681, January 2013.

[2] T. E. Fatoyinbo, M. Simard, R. A. Washing-Allen and H. H. Shugart, "Landscape-scale extent, height, biomass, and carbon estimation of Mozambique's mangrove forests with Landsat ETM+ and Shuttle Radar Topography Mission elevation data," *Journal of Geophysical Research*, Vol. 113, G02S06, 2008.

[3] S. R. Cloude and K. P. Papathanassiou, "Polarimetric SAR Interferometry," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 36, no. 5, pp. 1551-1565, September 1998.

[4] R. N. Treuhaft, S. N. Madsen, M. Moghaddam, and J. J. van Zyl, "Vegetation characteristics and underlying topography from interferometric radar," *Radio Sci.*, vol. 31, no. 6, pp. 1449-1495, 1996.

[5] S. R. Cloude and K. P. Papathanassiou, "Three-stage inversion process for polarimetric SAR interferometry," *IEE Proceedings – Radar S4onar and Navigation*, vol. 150, no. 3, pp. 125 – 134, 2003.

[6] I. Hajnsek, F. Kugler, S.-K Lee and K. P. Papathanassiou, "Tropical-Forest-Parameter Estimation by means of Pol-InSAR: The INDREX-II Campaign," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, no. 2, pp. 481-493, February 2009.

[7] G. Krieger, A. Moreira, H. Fiedler, I. Hajnsek, M. Werner, M. Younis and M. Zink, "TanDEM-X: A Satellite Formation for High-Resolution SAR Interferometry," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 11, pp. 3317-3341, November 2007.

[8] INFOTERRA, "Radiometric Calibration of TerraSAR-X Data: Beta Naught and Sigma Naught Coefficient Calculation", *INFOTERRA*, Friedrichshafen, Germany 2008.

[9] R. Z. Schneider, K. P. Papathanassiou, I. Hajnsek and A. Moreira, "Polarimetric and Interferometric Characterization of Coherent Scatterers in Urban Area," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 44, no. 4, pp. 971-984, April 2006.

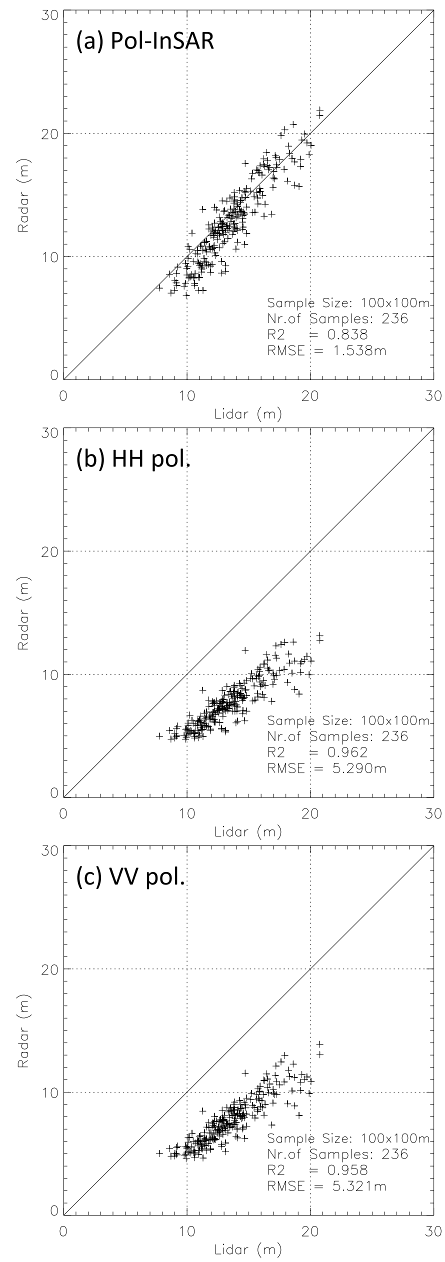

Figure 4 Validation plots lidar H100 reference height against Pol-InSAR inversion result (a), heights of phase center at HH (b) and VV (c).